Heat Exchangers: Classification and Applications in Food and Service Industries

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The heat exchange process between two or more streams at different temperatures happens in numerous industrial, commercial, and domestic applications and is usually affected in some type of a heat exchanger. The plate heat exchangers are widely used in warming, heating, cooling applications, food, and cosmetic and chemistry industry. The plate type heat exchangers are initially developed for the pasteurized liquid food domain which mostly requires hygienic application. Typical applications involve heating or cooling of a fluid stream of concern, evaporation, or condensation of a single or multicomponent fluid stream, and heat recovery or heat rejection from a system [1]. But, other than above these heat exchangers have a large application area in chemistry and food sector because of being compact and having the quality to be easily cleaned [2–6]. They can be broadly classified as either direct contact or indirect contact (or transmural) type of heat exchangers. In the former, the fluids transferring heat are in direct contact and not separated by a wall. Owing to the absence of a wall, closer approach temperatures are attained, and the heat transfer is often also accompanied with mass transfer [7].

Classification of Heat Exchangers

Heat exchangers may be classified according to transfer process, construction, flow arrangement, surface compactness, number of fluids and heat transfer mechanisms as shown in Fig. 1 modified from Shah [8] or according to process functions as shown in Fig.2 [9]. For the sake of article, a brief description of some of these exchangers majorly used in dairy & food industry classified according to construction is provided next along with their advantages and disadvantages over others.

Classification according to construction

Pipe-in-pipe heat exchangers

This kind of heat exchanger is widely used in chemical, food, oil and gas industries. Upon having a relatively small diameter, much precise research has also held firmly the belief that this type of heat exchanger is used in high-pressure applications. They are also of great importance where a wide range of temperature is needed. It is also well documented that this kind of heat exchanger makes a significant contribution to pasteurizing, reheating, preheating, digester heating and effluent heating processes [10].

Equipment consisting of two pipes with different diameters inserted one into the other. With the help of clutch couplings, all parts of the pipes are assembled into a coil, which provides the necessary space for the heating and cooling medium. Sections are placed one above the other. The flows are directed counter-currently (towards each other). The cooling agent comes from below, and after heating rises. The heated steam accumulates from above. After condensation, it goes to the bottom of the heat exchanger. This heat exchange equipment is used in the food industry. Heat exchangers of this design are characterized by a significant heat transfer coefficient and can operate at high pressure. The pipes are cleaned mechanically on level areas. The flow inside the two-pipe heat exchangers can be parallel or counter-current [11].

The main advantages of the device of this design include:

a) High flow rate of the coolant: this is achieved through careful selection of water pipes of the desired diameter, which allows the medium to flow freely inside the pipes.

b) Ease of maintenance: This property makes it possible to carry out regular cleaning of equipment, which allows to increase the duration of its operation.

c) Versatility: In systems, it is permissible to use a coolant both in the liquid and in the vapor phase.

The disadvantages of the equipment are:

a) Dimensions: due to the large size, difficulties arise during transportation and use of the device. Most of all this refers to individual use, where space is very limited.

b) High cost: the price of external pipes that are not involved in heat exchange, and which are connected to the heat exchanger, is quite impressive.

c) Difficulties in the design: when choosing this equipment, you must contact the professionals, which is associated with the complexity of the calculation. At the same time, the overall cost of manufacturing and installation work increases.

Shell-and-tube heat exchangers

When the required heat transfer surface is large, the recommended type of heat exchanger is the shell-and-tube. In this type of heater or cooler, large heat-transfer surface can be achieved economically and practically by placing tubes in a bundle, the ends of the tubes are mounted in a tube sheet. This is very commonly accomplished by expanding the end of the tube into a close-fitting hole in the tube sheet by a process called rolling. The resultant tube bundle is then enclosed by a cylindrical casing (the shell), through which the second fluids flow around. They are used as evaporators and condensers. Depending on the operating conditions of the equipment, it is installed in a vertical or horizontal position [12].

In multi-way devices, it is necessary to firmly fix the base and pipe sections. Such modules function even with a small difference in temperature of the working environment. When choosing the material of the heat exchanger, it is necessary to consider the aggressiveness of the environment. Due to the inaccessibility of the heat exchanger tubes, the formation of corrosion is highly undesirable. Cleaning is carried out exclusively by a chemical method [13].

The advantages of the devices are:

a) Internal reliability: Shell-and-tube heat exchangers are more resistant to scale formation, which implies that cleaning should be done less frequently than with other heat exchangers.

b) Possibility of power regulation: If necessary, increase or decrease the power, adjust the number of

c) Sections: the length and diameter of the pipes.

d) Long service life: Shell-and-tube heat exchangers have a long service life.

The disadvantages of the equipment are:

a) Large dimensions. A heat exchanger weighing 120–150 kilograms and a length of 4 meters cannot always be fitted and installed at the facility.

b) Vulnerability of the outer part of the case. Tube heat exchangers are made of electric welded pipe. After a short period of work, the outer coating begins to diverge along the seam, leaks appear, because of which oxygen begins to be released when the water is heated. This contributes to the development of metal corrosion [14].

c) Efficiency. The coefficient is only 70%, which increases energy losses.

Plate Heat Exchangers

A popular heat exchanger for fluid of low viscosity, such as milk is the plate heat exchangers, where heating and cooling fluids flow through alternate tortuous passages between vertical plates. The plate heat exchanger is commonly used in HTST units, for heating temperatures which are below the boiling point of milk. The advantages are highly efficient, occupy less space, compact, simple easily cleaned, low in cost, versatile, sanitary easily inspected and can be used for heating, cooling, regeneration and holding.

They consist of many corrugated plates made of stainless steel. They are separated by seals that are installed without the use of adhesive mixtures but allow tight fit to each other. Gaskets provide absolute tightness and do not allow mixing of media. The choice of material of the heat exchanger must be carried out depending on the technological process, the type of coolants in the system, temperature load and pressure. The most universal in application: plate heat exchangers made of stainless steel with copper pipes [15].

The advantages are:

a) High efficiency. Due to the large area of the heat exchange surface, the efficiency reaches 95%, which is much higher than that of tubular apparatuses.

b) Compactness. The device is selected in accordance with the required heat consumption. With a small number of plates, the differences will be less, respectively, with a larger number of plates, the differences will increase.

c) Multifunctionality. Plate heat exchangers are used in many areas of life, have a wide range of capacities.

d) The cost of the device depends on the number of plates installed in it. There is the possibility of selecting the right number of plates. Repair costs replacing a worn (damaged) plate, and not the entire system.

The disadvantages of the equipment are:

a) Short service life. Plate heat exchangers are quickly clogged. The maximum service life without cleaning is 3 years.

Spiral plate heat exchangers

Spiral plate heat exchangers are made of two metal plates that are wound on each other. One stream of process fluid enters the heat exchanger through the centre and flows from the outside, while the second stream enters from the outside and flows inward. This creates a close to natural backflow [16].

The advantages are:

a) Single flow paths reduce the rate of scale build.

b) Ability to work with two highly polluting liquids.

c) Lack of dead zones for accumulation of solid particles inside the heat exchanger

d) Counterflow.

e) Made of many alloys.

f) Very low pressure drops.

The disadvantages of the equipment are:

a) Designs are the intellectual property of companies, a limited number of manufacturers.

b) As a rule, the design is more expensive than other types of heat exchangers.

Spiral tube heat exchangers

Spiral tubular heat exchangers are made of spiral pipes. In some cases, the tube is installed inside the bundle to ensure the compactness of the heat exchanger. In this, Heating or cooling medium flows in one direction. Product counter-flows in the opposite direction. In construction of these PHEs Gasket, clamps, bolted fittings and packing glands

are avoided, producing constant flow area throughout the entire unit, even return bends. These heat exchangers are mainly used for small capacities [17] and can be mounted on walls floors or ceilings.

The advantages are:

a) Compact and inexpensive heat exchanger requiring low power.

b) Can withstand high pressures.

The disadvantages of the equipment are:

a) Designs are the intellectual property of exchanger-a limited number of manufacturers.

Air-cooled heat exchangers

Air-cooled heat exchangers use ambient air to cool and condense the working medium. They are usually used in places where there is a shortage of cold water. Air-cooled heat exchangers are commonly used when the temperature at the outlet of the heat exchanger is at least 20° C higher than the ambient temperature. They can be designed for closer temperatures, but often become expensive compared to a combination of a cooling tower and a water-cooled heat exchanger. Air-cooled heat exchangers use electric fans to move air through a series of pipes [18]. There are two main mechanisms:

a) Induced draft fans draw air through the tube blocks.

b) Fans blow air through a series of pipes.

Air-cooled heat exchangers are expensive compared to water-cooled heat exchangers due to their large size, low air heat transfer coefficient, and structural and electrical requirements. In addition, air cooler heat exchangers require large surface areas of pipes and must be designed in such a way as to withstand daily and seasonal changes in air temperature [18]. The low heat transfer coefficient associated with the flow around the air of the outer sides of the pipes is partially overcome due to the wide use of finned pipes to increase the outer surface area. Changes in ambient temperature are often controlled by fans with a variable speed or airflow adjustment step. In cold climates, it may be necessary to develop a design with the ability to recirculate air to prevent freezing during operation. Smaller heat exchangers (like radiators) are used for small areas of responsibility [19].

Advantages of Air-cooled Heat Exchangers

a) Do not use water for cooling.

Disadvantages:

a) Requires a large area of the site.

b) High manufacturing costs.

c) Ribs may become clogged in dirty environments.

d) Fans may make noise.

Application in Food and Service Industries:

Heat Exchangers which are starting from its dairy industry origins for milk pasteurization, the modern-day applications of Heat Exchangers have expanded considerably to encompass a variety of different industries and processes.

1) Food processing

A general categorization of the food processing industry includes dairy products (e.g. milk, yoghurt, cream, and ice cream), brews and distilled products (e.g. wort, beer, wine, and alcohol), beverages (e.g. juice, carbonated drinks, tea, and coffee), and processed fruits and vegetables (e.g. purees, pastes, sauces, and jams). Here, pasteurization is perhaps one of the most important processes involved. There are several reasons why PHEs have been widely used historically as well as in present times for milk pasteurization. Perhaps the two most prominent factors are: (1) PHEs can be easily opened and thoroughly cleaned, and with

plates made of high-grade stainless steel, this ensures maintenance of very stringent hygienic requirements and (2) the high heat transfer coefficients promoted by their corrugated inter-plate channels permit very close approach temperature difference (as low as 1◦C) operation.

Pasteurization is also required in a variety of foods and beverage processing, including fruit juice, tomato paste, cream, whey, ice cream, beer, wine, etc., and PHEs are increasingly being used in most systems. In food processing applications, typical examples are sensible heating and cooling in pre-treatment and fermentation, drying, blending, freezing, sterilization, as well as phase change (boiling/evaporation) in cooking, forming pastes, crystallization, and polymerization.

Air-conditioning and refrigeration systems

In the past several decades, the high demands from residential comfort, commercial climate control, and food, biological, and biodegradable material preservation, etc., have greatly increased the general usage of heating, ventilation, air-conditioning, and refrigeration (HVAC&R) systems. For example, in a central comfort cooling or building air-conditioning system, the main chiller segment is essentially a vapour-compression refrigeration cycle unit: compressed refrigerant vapour flows through the condenser (heat sink), the exiting liquid refrigerant then expands through the throttle valve, low-pressure liquid refrigerant then flows through the evaporator (heat source), and the outlet vapour is finally fed to the compressor again to complete the cycle. The secondary heat exchange units, both on the condenser and evaporator sides, usually operate with cold water or water–glycol solutions as working fluids.

In the refrigeration system, PHEs (particularly brazed or welded types) are increasingly being employed as a condenser or evaporator directly in chiller units, as they have been found to provide a viable high-performance alternative to the traditional tube-fin type heat exchangers [20–23].

Service heating and cogeneration

Previously heating, is needed to provide a comfortable indoor environment in residential, commercial, office, and public facility buildings. However, heating needs are now increasingly required for a variety of other services that include, among others, tap water, swimming pools, and greenhouses. All heating applications are generally divided into two categories, based on several major differences:

a) service heating b) district heating,

Service heating systems normally have the heat source inside and it is supplied only to a single building. The heat source is normally not only a boiler, but it can also come from heat pumps and solar panels. The normal operating temperature is below 100◦C and the pressure is 6 bar or below for these systems. In contrast, district heating systems distribute hot water or steam to multiple buildings (and, in some cases, to an entire township). A variety of heat recovery from industrial systems. Their normal operating temperature and pressure are, respectively, 100–150°C and 16 bar.

In both types of systems, PHEs can serve both as the condenser and as the secondary heat exchanger. Their close approach temperature difference operation makes the system more energy efficient, and this economic incentive is further supplemented by the much smaller space needed for PHEs as compared to shell-and-tube heat exchangers [20–23].

Chemical processing

Chemical processing generically encompasses many different types of industrial applications in petrochemicals, pharmaceuticals, oil or gas production and delivery, and manufacture of organic and inorganic chemicals, to name a few. In all these applications, heat transfer plays a centrally important role and has a significant impact on the process efficiency, product delivery and reliability, and plant economics. To illustrate the role of heat exchangers, and PHEs, four typical thermal processes are described in this section, namely, evaporation, absorption and stripping, distillation, and reactor temperature control. These processes are representative of the chemical industry applications in general, and clearly highlight the advantages of selecting PHEs. Plate evaporators today can be found in sugar factories, distilleries, paper mills, alkali and alumina plants, pharmaceutical production, and the manufacture of many inorganic salts and organic chemicals such as ethylene glycol, detergents, personal hygiene products, and glycerol.

Absorption and stripping are principally a way of recovering volatile organic compounds. While the economic incentive for this is to minimize the consumption of solvent, it is also increasingly a legal requirement to meet the newer more stringent environmental impact regulations. The system efficiency improvement essentially requires maximization of the heat recovery and minimization of the external heating and cooling utilities. Close approach temperature difference operation facilitates this and PHEs clearly have an advantage over traditional shell-and-tube heat exchangers. Moreover, with counter-current flows in PHEs as well as with conventional shell-and-tube units.

Distillation unit system consists of a condenser and a reboiler placed, respectively, at the top and bottom of the distillation column. For the condenser duty, PHEs are very attractive because they are small and light and are thus easy to be mounted on top of a distillation column, saving space and reducing installation costs. Like the condenser, PHEs are suitable as reboilers mounted at the bottom as well, taking up minimum space and requiring minimum piping.

Pulp and paper industry applications

As pulp and paper mills adopt closed water cycle systems, it has become more and more important for plant operators to focus on energy and water management. Inducting PHEs in such applications can provide viable solutions as well as meet new environmental requirements. Standard PHEs readily meet all of these constraints, except for handling fibrous media. For those applications with fibers in one stream, the single-side widegap PHE can be used, a double-sided wide-gap plate pack is used in cases where both fluid streams have fibrous content.

Typical applications involving PHEs in pulp and paper mills include cooling of bleaching plate filtrate by heating of process water (waste-heat recovery), heating of intermediate black liquor by cooling of evaporation condensate, heating of wire pit white water by condensation of steam, and heating of fouled condensate before stripping by cooling of clean condensate after stripping, among others.

Conclusions

The content presented in this article involves some of the majorly used types of heat exchangers in Dairy, Food and beverages industries but also highlighted the importance of heat exchangers (PHEs & Shell and tube) in different industries includes chemical, paper, refrigeration, and other

service industries. Since due to diversity and complexity of topics related to heat exchangers it is a vast subject to cover in one article. Space limitation, however, has prevented the authors from thoroughly covering many equally important aspects of design and operation of heat exchangers. The examples briefly outlined in this article are quintessentially representative and serve as an introduction to readers. Many other industries, such as pharmaceuticals, electronics and electrical equipment, steel and metal industry, motor vehicle industry also use heat exchangers. However, in some of these cases special and customized exchangers may be needed.

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